Military Unmanned Ground Vehicles

International Development Activities

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Introduction

NATO & International UGV R&D Activities

NATO RTO R&D Activities

- Unmanned systems are prevalent in numerous NATO R&D activities as both the focus of R&D topics (platforms) or as a subset of other topics (ISR)

  -- However, attention to UAVs far outpace attention to UGVs

- Nonetheless, R&D efforts in both areas above provide insights into foreign military UGV capabilities & R&D activities while identifying key participants

- Background: NATO's Research & Technology Organization (RTO) promotes cooperative R&D & S&T exchanges among 26 nations & 38 partner countries

  -- Largest international collaborative body, 3,000 subject matter experts (SMEs)

- RTO operates by "organizing studies, workshops, symposia & other forums" through Working Groups (WGs) from RTO's 6 Technology Panels (TPs):

Applied Vehicles	Human Factors & Medicine	Information Systems
System Analysis	Systems Concepts & Integration	Sensors - Electronics

- RTO generally does not fund R&D (e.g. grants, contracts) nor does RTO typically initiate cooperative R&D ventures (e.g. CRADAs)

  -- RTO mostly supports (NATO-only) symposiums (50 - 100 SMEs) & joint analytic projects of small (~12 SMEs) study groups (SGs) -- (~45 SGs total)

NATO RTO UxV - UGV R&D

- A initial review of 6 NATO RTO TPs & quick scan of related TP SGs, show UxVs & related technologies were popular subjects & many aspects are addressed by numerous TPs
- Surprisingly, there does not exist an individual NATO RTO TP on UxVs in general or UGVs specifically
- UxVs & UGV TP activities seem more focused on new technology developments vs. expanded application of existing technology to broader warfighter capability needs (e.g. CONOPS, TTPs, DOTMLPF)
- Numerous UxVs & UGV R&D activities are currently underway or recently concluded among NATO's 6 TPs & various WGs

NATO RTO TP Research Task Groups (RTGs) on "Multi-Robot Systems & Military Applications"

- One (multi-phase) WG of particular note (2001 through December 2007) was the Information Systems TP's (IST) Research Task Groups (RTGs) on:

  [1] "Multi-Robot Systems in Military Domains" (IST-032 / RTG-014) &

  [2] "Military Applications For Multi-Robot Systems" (IST-058 / RTG-024)

  -- Maintained a long-term focus & emphasis on UGVs (vs. other UxVs)

  -- Undertook unique efforts (2004 - 2005) to forecast military UGV capability needs, warfighter requirements & UGV technology-industrial base capacity

  -- Related results where used to identifying near-term military capability "gaps" & "gaps" in future technology-industrial base capacity (2004 - 2008)

  -- Outcomes included the development of requirements analyses & notional technology roadmap as well as identification of UGV R&D investment priorities

- RTG activities concluded in December 2007 & a final report is due in 2008

NATO RTG UGV 2004-2008 Roadmap Exercise Needs, Requirements & Technology Gaps

<table>
<tr><th>Military Capability Needs</th><th>Military Requirements</th><th>Technology Gaps</th></tr>
<tr><td rowspan="2">Reconnaissance and surveillance for tactical support for forces on the ground including NBC</td><td rowspan="2">Communications (COMS): mobile, wireless ad-hoc, high ranges / rates, multipoint, QoS compliant, prioritize data, secure, network availability adjustable</td><td>COMS system should meet requirements but current tech does not support all requirements at same time</td></tr>
<tr><td rowspan="2">Platform: SOA power cells, efficient motor drive / power train, refined transition / suspension, lower mass / armored, lower workload, EMC hardening</td></tr>
<tr><td>De-mining (tactical-post-conflict) clearing roads, fields (anti-tank / anti-personnel).</td><td>Platform: mobility, ruggedness, EMP shielded, low manning burden, modular concepts, greater standardization (power, connectors)</td></tr>
<tr><td>Convoying, transport of goods</td><td rowspan="2">Sensing & World Modeling (S&WM): World modeling for navigation & mission execution, high on-board processing capacity & information</td><td rowspan="2">S&WM: multi-sensor suite fusion - more robust world view, obstacle avoidance, terrain modeling, UXO/OED & NBC sensors, environmental mapping, sensor fusion, object detect-recognition</td></tr>
<tr><td>Inspect vehicles and people for explosives and weapons at checkpoints.</td></tr>
<tr><td>Carry equipment for dismounted solider</td><td>Navigation & Mission Planning (N&MS): Mission planning, path planning and navigation; sensor information distribution and distributed behavior communication and coordination (e.g. JAUS)</td><td>MRS: multi robot interaction different-same tasks, collaborative tasks, autonomously divide a task, cooperative perception, autonomously manage-prioritize</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Multi-Robot Systems (MRS): workload sharing, distributed sensing, cooperative-collaborative behavior, fully distributive / hierarchical control</td><td>N&MS: autonomous road following, mixed traffic, moving in tactical behavior, follow the leader</td></tr>
<tr><td rowspan="2">HRI: <50% workload simple terrain / <75% difficult terrain, execution plan in advance of maneuver, wearable interface, evaluate performance measures, improved ergonomics, common interface</td></tr>
<tr><td>Human Robot Interaction (HRI): Upgrade from continuous manual remote controlled to supervised autonomous</td></tr>
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NATO RTG Roadmap Exercise Observations

- Said to be the first effort of its kinds (likely regarding a multi-national military UGV “requirements development & technology roadmapping” initiative)
- Interesting note about importance of standards & reference to JAUS
- Nevertheless, self-assessed need for broader involvement of NATO military & warfighter inputs concerning UGV CONOPS, TTPs & DOTMLPHF issues
- No apparent references found about counter-IED needs (vs. possibly more conventional de-mining applications) or counter-sniper / counter-mortar
- No needs identified specific to the weaponization of UGVs (possible ethical concern) & limited reference to target acquisition for precision weapons
- No reference found concerning application of lessons-learned relative to UGVs & OEF / OIF or those specific to urban reconnaissance-surveillance needs
- Finally, detailed mention was observed concerning opportunities for UGV experimentation & simulation of future military UGV CONOPS & TTPs
- Overall, this RTG exercise seems to be an impressive & novel effort between NATO militaries, defense firms & research organizations

NATO RTO RTG
Recommendations & Developments (2004-2008)

- Recommendation for multi-nation military UGV R&D investment campaign & increased warfighter customer & requirements community participation
- “A problem is that military users are interested in UGVs but have to consolidate funding” & “current research is ad hoc & no real user pull”
- Recommendation for a “European version of DARPA” & “lobbying for funding & defense research demands”

  -- cooperation should come from military users (war fighters) from various countries” (2005)
- Recently revealed (late 2007) the European Defense Agency (EDA), is taking on role to advance EU military UGV R&D & investment (next section)

  - However, US-firms & DOD are generally restricted from EDA participation
- Other RTG activities include close collaboration w/ European Robotics Network (EURON) illustrating value of commercial & academic innovation
- RTG instrumental in the creation of the newly established (2006) European Robotic Trails (ELROB) to assess EU’s UGV state-of-the-art (next section)
- NATO said to be forming new RTG to address deconflicting & harmonization of interoperability standards (e.g. JAUS vs. NATO STANAG) (next section)

Additional NATO RTO UGV-UxV R&D Activities

Information on additional NATO RTO UGV-UxV activities are listed below which provide useful insights into other international military UGV-UxV current capabilities, near-term R&D activities & key participants:

RTO-MP-AVT-146: Platform Innovations & System Integration Unmanned Air, Land & Sea Vehicles: RTO Applied Vehicle Technology Panel (AVT) Symposium, Florence, Italy, May 2007

RTO-MP-HFM-135: Human Factors Uninhabited Military Vehicles as Force Multipliers: RTO Human Factors & Medicine Panel (HFM) Symposium, Biarritz, France, October 2006

RTO-TR-HFM-078: Uninhabited Military Vehicles: Human Factors Issues in Augmenting Force (2002 - 2006): RTO Human Factors & Medicine Panel (HFM) TG HFM-078/TG-017

SCI-144: Integration of Systems with Varying Levels of Autonomy (2004 – 2007)

NATO-US & International UGV Technology Standards

International Standards & Harmonizing UxV Interoperability

- Further UGV technology development & greater utilization face challenges:
  - International barriers to accelerating innovation & faster technology transition
  - Impediments to broader systems integration & increased interoperability
- With rapidly changing technology, increasing globalization of manufacturing supply chains & internationally distributive product development

  ....internationally adopted standards are crucial to commercial, defense & dual-use industrial base integration & increased competitiveness
- Dynamic & unpredictable national security & homeland defense scenarios

  ....require fast-forming coalitions (locally & abroad), responsive net-centric enabled systems & transformational military capabilities

  ...all are dependant on interoperability to communicate, coordinate & collaborate
- Interoperability standards also support key UGV acquisition goals:
  - Lower life cycle costs, faster development time & quicker product integration
  - Open standards further support common interface for technology insertion
  - Enable expansion of existing systems w/ additional (spiral-on) capabilities

DOD / SAE AS-4 "JAUS" Standard

- To facilitate greater interoperability of future US unmanned systems ...new standards were developed by DOD & industry
- DOD developed the Joint Architecture for Unmanned Systems (JAUS) as the interoperability standard for UGVs (Army in 1994, OSD in 2002)
  - Primarily for communications & data handling for UGV command & control
  - Applicable at the system level as well as subsystem & component level
  - Consistent with US Government (USG) policy DOD transitioned JAUS to the private sector & the international Society of Automotive Engineers (SAE AS-4)
  - DOD UGVs utilize JAUS as do Army UAVs & Unattended Ground Systems (UGS) for Future Combat System (FCS)
  - As UxVs proliferate with state-local authorities, so will the use of JAUS standard
  - For example, National Bomb Squad Commanders Advisory Board (NBSCAB) requires EOD robots to be JAUS-compliment when purchased w/ USG funds

NATO “STANAG 4586” Standard

- NATO established Standardization Agreement (STANAG) 4586 in 1996
- Following a NATO Industrial Advisory Group (NIAG) study on tactical UAV system interoperability
- 4586 supports a standard interface of the Unmanned Control Systems (UCS) for NATO UAV interoperability (established 2002)
- The goal is to support NATO “multinational UAV interoperability”
- Specific objective is “to provide a standard for three key interfaces”
  - Data Link Interface (DLI)
  - Command and Control Interface (CCI)
  - Human Control Interface (HCI)
- Applicable at the system level vs. the subsystem & component level

SAE AS-4 (DOD) JAUS VS. NATO STANAG 4586

JAUS & STANAG evolved to the most common standards for unmanned systems

However, JAUS & STANAG are not fully interoperable:

- Among full UxV spectrum (all domains) as well as unmanned-manned systems
- Across DOD Services, NATO & coalition allies as well as state-local authorities

  - Example: NATO, US NAVY & AF UAVs use STANAG (plus Navy USVs & UUVs) which raises question of interoperability of UGVs in littoral & riverene environs
- In addition, DOD-NATO interoperability challenges exist w/ UAVs & STANAG
- Another twist: USG policy support of open industry standards & the goal of USG standards to "promote efficiency & economic competition"

  - Example, STANAG 4586 is NATO "UNCLASSIFIED" (but NATO-only) restricting access to many global suppliers & non-traditional innovators from non-NATO countries such as robotics industry leaders in Japan & South Korea

  - Could similarly conflict with civilian state-local authorities & their supplier base relative to USG technology transfer authorities & impeded interoperability of related commercial dual-use systems with military systems

Future JAUS VS. STANAG Questions-Issues

- Unknown extent of the future use of JAUS vs. STANAG by foreign military UGVs vs. foreign law enforcement UGVs given they often share common equipment
- Foreign UGV manufacturers may often use proprietary standards
  - Example, U.K.-based, QinetiQ's use of Common Interface Protocol (CIP)
- Foreign *"home grown"* standards possibly common as UGVs traditionally used locally in stand alone scenarios vs. systems-of-systems of international coalitions
- This will change as future teams of UxVs (& manned systems) evolve globally
- It may be likely that foreign UGV companies will develop future UGVs around JAUS in to order compete for export opportunities within the world's largest JAUS-compliant defense & homeland security market
- Will US firms selling JAUS systems to DOD proliferate JAUS internationally through exports given US lead in military UGVs & defense exports overall
- With the flood of US & foreign STANAG-compliant UAVs (& quarter century lead & growing integration w/ other systems) ....is STANAG positioned for growth

Efforts to Harmonize International Standards

- According to DOD's new Unmanned Systems Roadmap: US is engaged in working with nearly a dozen NATO countries on improving STANAG UAV interoperability

- Although no formal mechanism is in place between DOD and NATO on working through like kinds of interoperability challenges with JAUS -- current efforts between DOD and NATO on improving UAV interoperability with could serve as an effective entrée to harmonize JAUS & STANAG

- Recent news of a new effort getting underway in Europe with the possible creation of a NATO RTO Working Group on harmonizing standards across multiple UxV domains as well as between unmanned & manned systems

- Growing momentum exist for DOD & NATO to collaborate on harmonizing interoperability standards for UGVs as well as the full spectrum of UxVs across all domains

NATO-EURON & European Robotic Trails (ELROB)

European Land-Robot Trial (ELROB)

- Annual field robotic demonstration of state-of-the-art (SOA) UGV capabilities for military & related civilian applications (est. 2006 & 2007)
  - annually alternating between military (2006) & civilian applications (2007)
  - sponsored by NATO RTG & European Robotics Network (EURON) & hosted by German MOD
  - goal is to stimulate European UGV innovation & expand industrial base .... by encouraging UGV cluster development & multi-country collaboration as well as leveraging R&D investment & increasing market awareness & demand
- ELROB first hosted 20 European teams from 5 countries in Germany (2006)
  - 600 spectators from 19 countries
  - military scenarios in both urban & non-urban environments
  - focused on vehicle mobility & reconnaissance-surveillance applications
- ELROB is considered a one-of-kind window into Europe's SOA UGV capabilities
- ELROB excludes direct US firm participation although EU-based US subsidiaries (or potential EU teaming possibilities) may possibly enable US involvement
  -- non-EU observers are welcomed to attend

EU-EDA & International UGV R&D Activities

European Defense Agency (EDA)
Multi-Government Military UGV R&D Initiatives

- EDA created in mid-2004 as an agency of the European Union (EU) & governed by Ministries of Defense (MODs) of 26 participating EU states
- Objective: Increase shared-use of military equipment between EU member nations & support of multi-country defense industrial base collaboration & R&D partnerships
- Goal: Increase cost-effectiveness & affordability of equipping EU armed forces while strengthening the international competitiveness of EU's defense technology-industrial base
- First of 4 EDA initiatives in 2005 included development of an Armored Fighting Vehicle (AFV) Roadmap & 2 associated feasibility studies (Networked Enabled AFVs & Unmanned Ground Tactical Vehicles)
- Feasibility studies resulted in recent launch of 3 military UGV R&D programs in late 2007 & subsequent start of a 4th UGV program in December 2007
- Combined level-of-effort (LOE) of 4 UGV R&D programs initially ~$30M USD
- Non-European country MODs & companies are generally excluded from directly participating in EDA R&D programs

EDA Military UGV R&D Program 1: "Semi Autonomous UGV" (SAM)

- Scope to included identification of:
  - Existing, state-of-the-art (SOA) UGV systems & subsystem technology & industrial base capabilities of EDA countries
  - UGV military capability gaps (primarily reconnaissance missions)
  - Corresponding UGV & subsystem R&D development projects
  - Latter will be used to formulate follow on UGV integrated development teams

- Applications aimed at UGV missions for patrolling, counter-IED & CBRN

- EDA German MOD Leads Program

  Industry Participation: Germany (Rheinmetall and Diehl BGT), Spain, France (Thales and Canberra Eurisys), Italy (Galileo Avionica) & UK (BAE Air Systems)

- Level of Effort (LOE): 4 years with 10M - 12M Euros (up to ~$17.5M USD)

EDA Military UGV R&D Program 2: "Use Robotics" (UGV)

- Program scope to include:
  - Develop generic "demonstration system" for UGV convoy applications
  - Likely intended platform(s) will be an existing "manned" vehicles
  - R&D program aim is to develop a UGV "modular conversion kit"
  - Various vehicles targeted in "several tons" class & upto 10 to 12 tons
  - Vehicles to operate in different environments & road conditions
  - Allow remote operator to supervise mission & take control when needed

- EDA Italian MOD Leads Program

  Industry Participation: Italy (CIO Consorzio Iveco - Oto Melara), Germany (Rheinmetall and Diehl), Greece (Hellenic Aerospace Industry), Spain (Espelsa), Finland (Patria Group), France (Thales), Poland (Edisoft), Portugal & (possibly), Cyprus

- LOE: 4 year, phase one 9 mo., 1.2M Euros - 1.4M Euros (~$2.07M USD)

- Subsequent R&D funding phase(s) to be determined after UGV MOD phase one requirements identified, industrial base capabilities assessed & gaps determine

EDA Military UGV R&D Program 3: "Networked Multi Robot System"

- Focus: "open architecture", software tool development effort
- Goal: Simulating (i.e. "test bed") networked, multi-robot ("collaboration") UxV systems in ground, air & sea domains
- Application area: C4I
- EDA German MOD Leads Program

  Industry Participation: Germany (Diehl BGT Defense and FGAN research center), Belgium (Royal Military Academy), Italy (Oto Melara of Finmeccanica), and Spain (Sener)
- LOE: 36 month, with $4.5M Euro (~$6.57M USD)

EDA Military UGV R&D Program 4:

"Generic Urban Area Robotized Detection CBRNE Devices"

(GUARDED)

- Demonstrating (presumably developing) remote controlled, mobile platform for detecting / sensing CBRNE devices (materials)
- Key aspects: High detection confidence & at a safe (stand-off) distance
- Sensor technologies of interest: Ground Penetrating Radar, Proton Transfer Reaction & Mass Spectrometry (through-wall & buried target detection)
- GUARDED is 1 of 3 new R&D Joint Investment Programs for EDA's Force Protection (JIP-FP) initiative
- JIP-FP is a new EDA initiative funded with 55M Euros (~$80.3M USD)
- EDA MOD Program Lead Unknown

  Industry participation: France (ECA & DDSC), Austria (Ion), Slovenia (IPS) & Finland (ENV)
- LOE: 3 years with 3.5M Euros (~$5.1M USD)

International Participation in DARPA Urban Challenge

Foreign Country Participation in DARPA's 2007 Urban Challenge

- Significant international involvement from foreign universities, industry & associated technology organizations:
  - 3 to 4 countries registered 6 to 7 teams including:
  - 1 team from Canada, 1 from France & 4 teams from Germany
  - 1 US team, AvantGaurd, (Israeli Elbit subsidiary) -- semi-finalist

- 2 German teams selected as semi-finalists:
  - Team Berlin (led by Frey University Berlin)
  - Team-LUX (industry led by Ibeo & STICK)

- 2 German teams selected as finalists:
  - Team AnnieWAY (Collaborative Research Center Cognitive Automobiles)
  - Team CarOLO (five institute collaboration of the Braunschweig University)

Foreign Technology Contributors to DARPA's 2007 Urban Challenge

- Germany S&T & industrial base also a major contributor to other teams:
  - Volkswagen of America's Electronics Research Laboratory (Palo Alto) partnered with Stanford University's Racing Team
  - Ibeo & SICK laser scanner navigation devices outfitted 53 out of 89 teams

- Italy plays key role in equipping US Team Oshkosh (formerly TerraMax):
  - Leading edge, stereo visioning system technology developed by Italy's University of Parma's VisLab
  - VisLab has a history of R&D collaborations with US industry on a number of DOD military UGV projects

- Additional international participation including:
  Australia, Austria, China, New Zealand & Mexico

Conclusions